Interannual variability in zooplankton biomass and relationships with the early marine survivals of Pacific salmon in the Salish Sea, BC, Canada

Kelly Young [1], Moira Galbraith [1], Akash R. Sastri [1], Antonio Velez-Espino [2], and R. Ian Perry [1,2]
E-mail: kelly.young@dfo-mpo.gc.ca

The availability of long time series of zooplankton data from the Strait of Georgia provides a means to understand the natural variability of this marine ecosystem. Perry et al. (2021) modelled the marine survivals of selected Salmon populations, and zooplankton variables were important in all models. Updates of the models continue to perform well against new data collected since the models were published (e.g. Figure 5, below)

Background

Many salmon populations in the Strait of Georgia (SoG, northern Salish Sea, Canada) have had high variability and huge reductions in abundance (Ruff et al., 2017). As part of the Canada – U.S. Salish Sea Marine Survival Program (Pearsall et al., 2021), we examined the roles physical conditions and zooplankton biomass and community structure had on the interannual variability of key Chinook and Coho Salmon populations in this region.

Zooplankton have been collected in the SoG sporadically since 1996, improving to monthly coverage since 2015 (Fig. 1). This analysis uses only the full-depth vertical plankton tows using Bongo or SCOR nets (60cm diameter, 250um mesh).

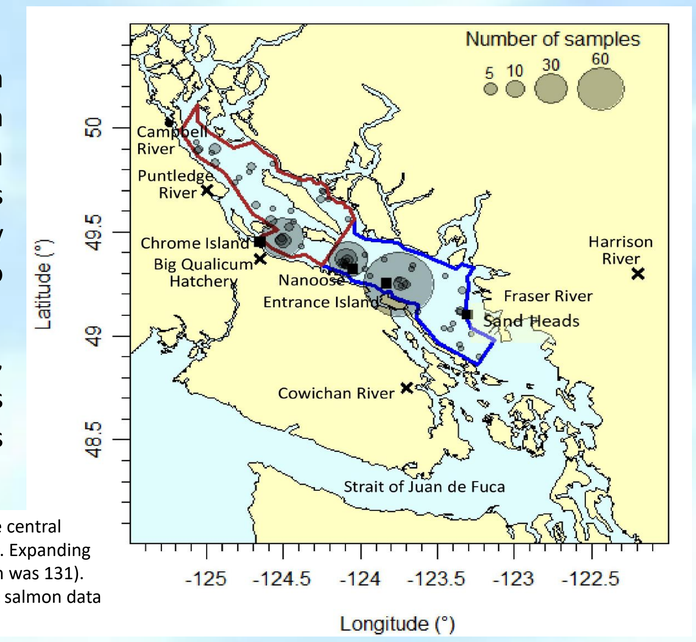
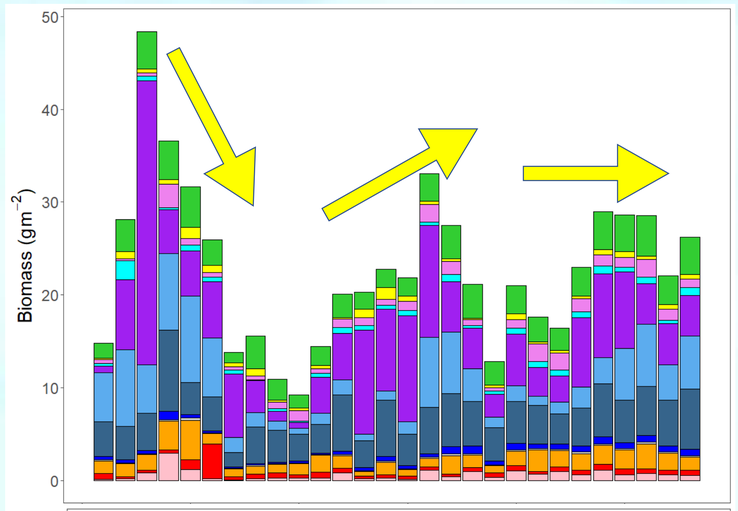


Fig 1. Location of the study and place names. Blue outline represents bottom depths greater than 50 m in the central Strait of Georgia, brown outline represents bottom depths greater than 50 m in the northern Strait of Georgia. Expanding symbols indicate the number of observations at each location (maximum number of observations at a location was 131). Black squares indicate the locations of the oceanographic or atmospheric data, and "X" marks locations of the salmon data used in this study. Map from Perry et al., 2021

The seasonal variability in the zooplankton data was removed by calculating annual log-scale biomass anomalies for selected species using an average seasonal cycle ("climatology", 1996-2010). This served as a baseline to compare seasonal conditions during any single year, which were then averaged within each year to give an annual anomaly (Mackas et al., 2013; Perry et al., 2021). We identified interannual trends of total zooplankton biomass and its major constituents, including those taxa identified as comprising important dietary items for Coho and Chinook. Physical data are collected throughout the SoG by DFO or Environment and Climate Change Canada (locations shown in Fig. 1).

Perry et al. (2021) developed statistical models comparing zooplankton and physical variables with the early marine survivals of selected Salmon populations which enter the Strait as juveniles based on data up to 2018. We provide an update to those models using data up to 2023.

What we Found



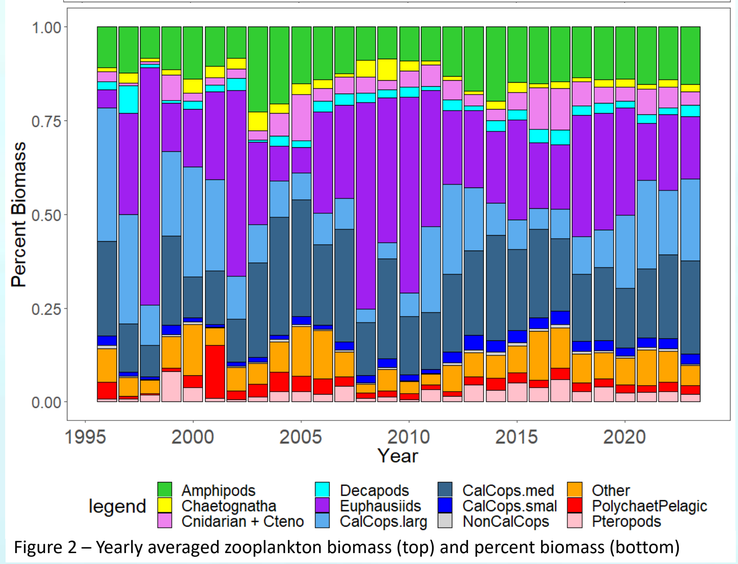


Figure 2 – Yearly averaged zooplankton biomass (top) and percent biomass (bottom)

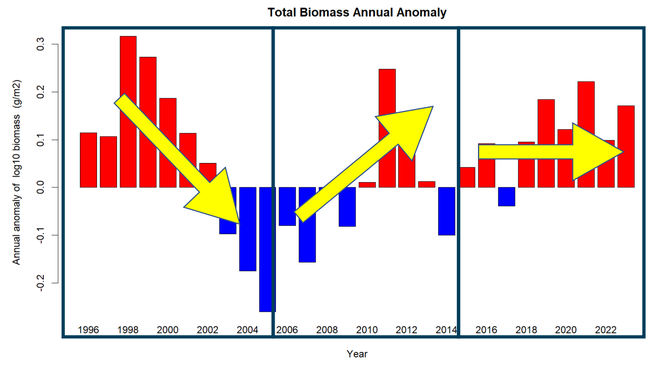


Figure 3 - Zooplankton total biomass anomaly overlaid with chronological clustering results showing 3 periods of declining, then increasing, and sustained above-average zooplankton biomass since 2015

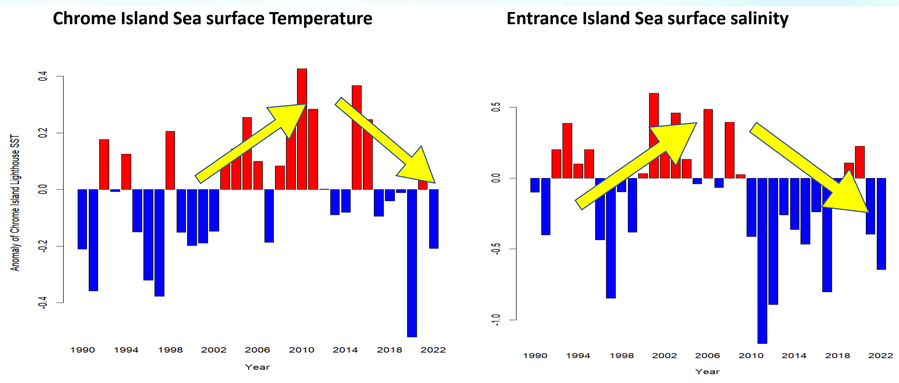


Figure 4 – Anomalies of key Physical data anomalies used in models in Fig. 5

DFO Lighthouse data https://www.dfo-mpo.gc.ca/science/data-donnees/lightstations-phares/index-eng.html
Environment and Climate Change Canada Weather station data
http://climate.weather.gc.ca/historical_data/search_historic_data_e.html

Total zooplankton biomass was dominated by large-sized crustaceans (euphausiids, large and medium size calanoid copepods, amphipods) (Fig. 2)

Annual anomaly of total zooplankton biomass was highest in the late 1990s, lowest in the mid-2000s, and generally above its climatological (1996–2010) average after 2011 (Fig. 3). Sea surface temperatures (SST) and salinities (SSS) generally increased until 2010; SSS and SST has been below average since 2010 (Fig. 4)

Perry et al. (2021) showed sea surface salinity at Entrance Island in the middle Strait of Georgia, the Pacific Decadal Oscillation, and the peak date of the spring phytoplankton bloom were significantly related to the zooplankton trends – generally declining zooplankton biomass with increasing salinities, and from 2015-on, increasing zooplankton biomass and decreasing salinities (yellow arrows in figures 3-4, above). This pattern has continued into 2023.

Selected zooplankton groups are important variables in the modeled early marine survivals of selected Chinook and Coho Salmon populations that enter the Strait as juveniles (Perry et al., 2021).

Updated modelling

The Cowichan River Chinook model (Fig. 5a) had the best fit (85% variability explained) and included three variables: annual anomalies of total zooplankton biomass (positive), annual anomalies of sea surface salinity measured at Entrance Island (negative), and annual anomalies of sea surface temperature measured at Chrome Island (positive). The model for the total marine survival of the Big Qualicum Coho population (Fig. 5b) had similar statistics to those for the Chinook populations and included two variables: annual biomass anomalies of total zooplankton, and small calanoid copepods; this was the only salmon model in Perry et al. (2021) which was entirely based on zooplankton variables.

Updated model predictions made since publications match well with current early marine survival estimation for Cowichan Chinook (Fig. 5a, red triangles and open circles). Updated Coho marine survival data are not yet available (Fig. 5b).

The uncertainty in the Coho model projections is quite large, reducing its usefulness for management decisions. However, these are total marine survivals derived from one year in the marine environment, whereas the model estimates are based on zooplankton data from the first year in the marine environment. The large residuals between modelled and observed survivals may indicate years in which the 'usual bottom-up' mechanisms controlling early marine survival (at least as represented by these simple models) broke down, i.e. years in which other factors may have dominated marine survival (e.g. 2011 or 2021 for Chinook).

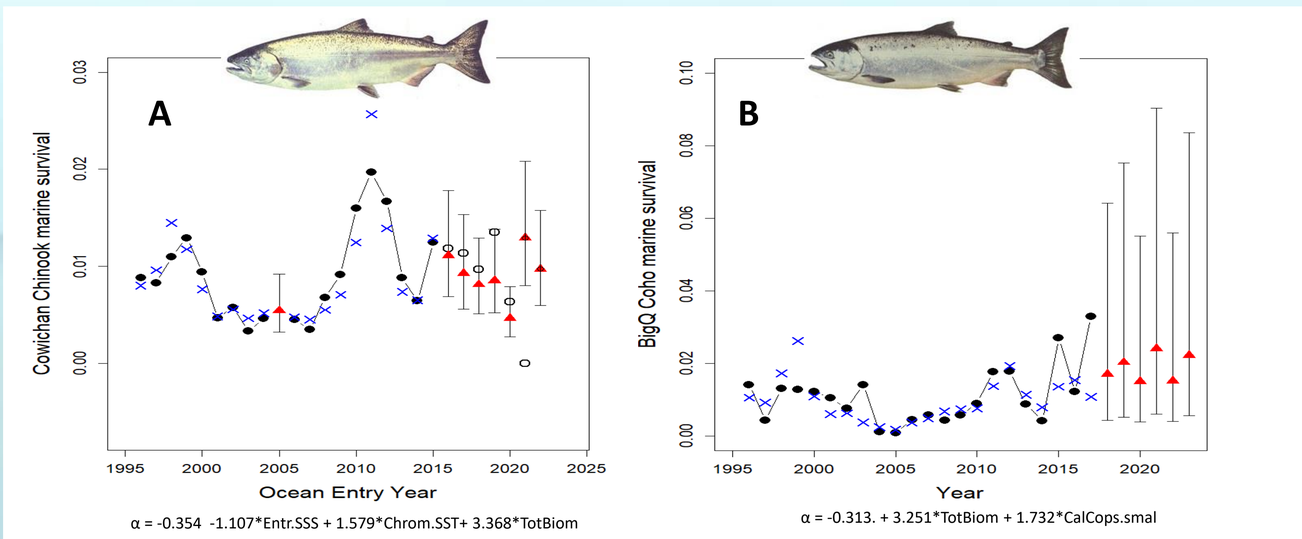


Fig 5 A: Cowichan Chinook early marine survivals compared with model estimates of early marine survivals based on Entrance Island sea surface salinity (Entr.SSS), Chrome Island sea surface temperature (Chrom.SST), total zooplankton biomass (TotBiom).
B: Big Qualicum hatchery Coho based on total zooplankton biomass (TotBiom) and small calanoid copepod biomass (CalCops.smal); These are also total marine survivals, derived from one year in the marine environment, where as the model estimates are based on zooplankton data from the first year in the marine environment.

Black dots and line: original marine survival data; open black circles: survivals estimated from incomplete returns; blue crosses: model fits; red triangles and vertical lines: predicted marine survivals and their 95% prediction (updated from Perry et al., 2021)
Salmon photos from Information about Pacific salmon | Pacific Region | Fisheries and Oceans Canada (dfo-mpo.gc.ca)

All of the models by Perry et al. (2021) for marine survivals of selected Salmon populations included zooplankton variables, and removal of the zooplankton variables markedly reduced the statistical fits. Although sea temperature was important in some relationships between zooplankton biomass and salmon marine survival, salinity was a more frequent and more important variable, consistent with its influence on the hydrodynamics of the Strait of Georgia system.

References:

Mackas, D., Galbraith, M., Faust, D., Masson, D., Young, K., Shaw, W., Romaine, S., Trudel, M., Dower, J., Campbell, R., Sastri, A., Bornhold Pechter, E.A., Pakhomov, E., El-Sabaawi, R., 2013. Zooplankton time series from the Strait of Georgia: Results from year-round sampling at deep water locations, 1990–2010. Prog. Oceanogr. 115, 129–159. https://doi.org/10.1016/j.pocean.2013.05.019

Pearsall, I., Schmidt, M., Kemp, I., Riddell, B., 2021. Factors limiting survival of juvenile Chinook Salmon, Coho Salmon, and Steelhead in the Salish Sea: Synthesis of findings of the Salish Sea Marine Survival Project. Version 1.0. www.marinesurvivalproject.com, www.psf.ca, and www.lltk.org.

Perry, R.I., Young, K., Galbraith, M., Chandler, P., Velez-Espino, A., Baillie, S., 2021. Zooplankton variability in the Strait of Georgia, Canada, and relationships with the marine survivals of Chinook and Coho salmon. PLOS ONE 16, 1–35. https://doi.org/10.1371/journal.pone.0245941

Ruff, C.P., Anderson, J.H., Kemp, I.M., Kendall, N.W., Mchugh, P.A., Velez-Espino, A., Greene, C.M., Trudel, M., Holt, C.A., Ryding, K.E., Rawson, K., 2017. Salish Sea Chinook salmon exhibit weaker coherence in early marine survival trends than coastal populations. Fish. Oceanogr. 26, 625–637. https://doi.org/10.1111/fog.12222

[1]Institute of Ocean Sciences, Sidney, BC, Canada.
[2]Pacific Biological Station, Nanaimo, BC, Canada

Fisheries and Oceans Canada | Pêches et Océans Canada

Canada